Increasing a nuclear plant's operating performance and efficiency

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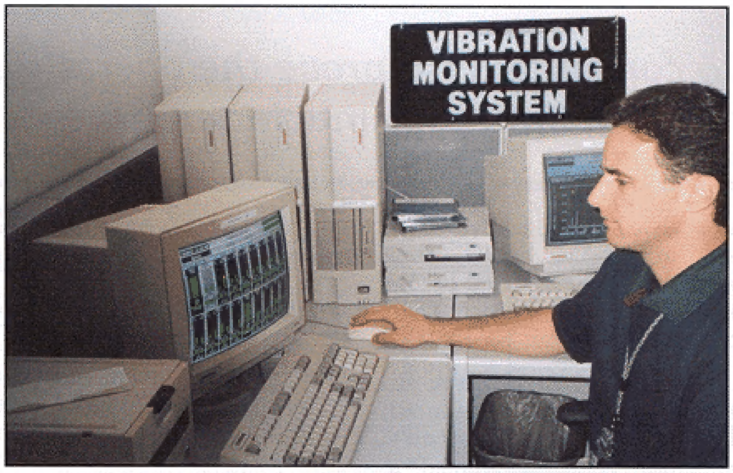
Bently Nevada machinery management systems are an important part of PECO Energy's commitment to operational excellence. At Limerick Generating Station, the machinery protection and management system enables them to operate more safely and efficiently. Limerick's goal is to continually improve the operating life and efficiency of its rotating machinery. PECO recognizes that part of that goal is to have timely and accurate information about the condition of their machinery, and part of the goal is knowledgeable personnel.

PECO Energy Company, one of the largest utility companies in the United States, operates nine generating stations, serving more than 1.5 million customers. It was founded in 1881 and was incorporated in 1929.

Limerick Generating Station's two General Electric, Boiling Water Reactors (BWR) can each produce over one million kilowatts of electricity, enough to supply 1.5 million households. Unit 1 went into commercial operation in February 1986; Unit 2 went online in January 1990. In 1992, Unit 2 set the world record of 533 days for the longest continuous operation of any commercial light-water reactor. Increasing efficiency and reducing downtime are major steps in preparation for increased customer demand and the deregulation of the utility industry.

Machinery protection and management

Bently Nevada 3300 Machinery Monitoring Systems and proximity probes monitor vibration on the following Power Generation and Reactor-related machines:



Anthony Dippolito, Component Engineer for PECO's Limerick Generating Station, accesses TDM2 data through the Data Acquisition Computer in the Technical Support Center.

- Main turbine-generator and exciter
- Condensate, Service Water, and Circulating Water Pumps
- Motor generator sets
- Reactor Recirculation Pumps (RRP)
- Reactor Feed Pumps (RFP)
- Emergency Core Cooling Systems consisting of:
  - Reactor Core Isolation Cooling (RCIC)
  - High Pressure Coolant Injection (HPCI)
  - Residual Heat Removal (RHR)

and

- Core Spray
- Control Rod Drive and
- Reactor Water Cleanup Pumps

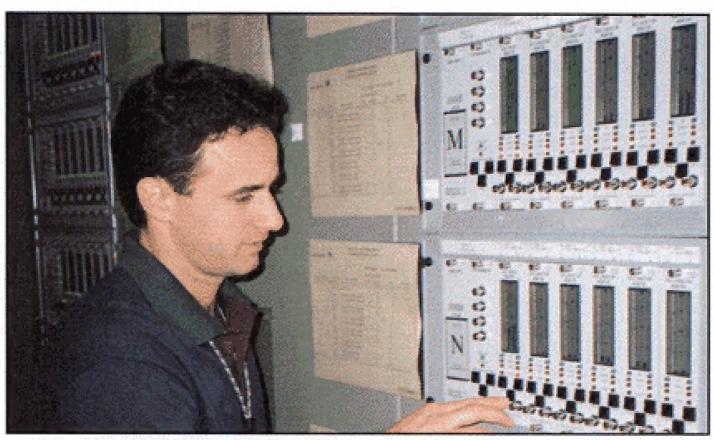
and other balance of plant pumps & motors.

Some balance of plant machines are equipped with velocity probes. All variable speed machines, as well as the turbine generator, are monitored by a Bently Nevada Transient Data Manager® 2 (TDM2) System which provides startup & shutdown data, as well as steady state data.

Today's monitoring systems interface directly to computerized systems. The data from the TDM2 is sent to three Data Acquisition Computers. These computers, located in the Technical Support Center, are connected by the plant Ethernet network to Display Computers in the control rooms of Units 1 and 2, and Site Engineering.

Operators in Units 1 and 2 display machinery information from all three Data Acquisition Computers. Operators can view machinery data from the 3300 Monitoring System and Communication Processors using Bently Nevada's Display Software, and from any other system computer on the network. The other Display Computer connected to the plant network is located in the Site Engineering Building. The Site Engineering computer is used by Component Engineers, who specialize in rotating equipment diagnostics, for immediate access to the information provided by the TDM2. One goal for Engineering is to make all system parameters available to the System Manager for long term trending to maximize system reliability and Maintenance effectiveness.

When additional information is needed to solve rotating machinery problems, Technicians from Engineering and Instrumentation and Calibration (I&C) use Bently Nevada's ADRE® for Windows and a 208 Data Acquisition Interface Unit (DAIU). This portable machinery data management system can sample up to 16 channels of dynamic vibration data during machine steady state or transient (startup or coastdown) conditions. It is easy to use, so data acquisition, reduction, and data reports can be generated with minimal user training. ADRE data has been used on numerous occasions for special testing and



The 3300 Monitoring Systems, which are immediately available to both Engineers and Operators in the Technical Support Center, provide data to the TDM2 System. This data can be accessed in Unit 1 & Unit 2 Control rooms and Site Engineering.

“Limerick’s goal is to continually improve the operating life and efficiency of its rotating machinery”

diagnostics. Some examples are, on Circulating Water pumps with severe misalignment and hydraulic unbalance, and on a Condensate Pump with bearing misalignment and electrical unbalance. The ADRE System can also diagnose vibration and monitor acceleration, strain, and pressure pulsations on the Main Steam line, Main Steam Stop and Control Valves, and High Pressure Coolant Injection steam supply line.

Limerick’s goal is to continually improve the operating life and efficiency of its rotating machinery. The TDM2 and ADRE for Windows Systems provide valuable machinery information that has helped Limerick manage its machinery more effectively and contributed to several machine saves.

Machine Saves

Main turbine generator

Approximately 30 days after a refueling outage, alarms on the turbine generator # 11 bearing (inboard exciter) were received in the Main Control Room (MCR). Operators immediately reduced reactor power until vibration levels could be reduced to below the 7 mil alarm setpoints. Engineering was immediately contacted to investigate. Over the next 24 hours, Engineering determined the exciter was experiencing a rub but could not explain why. The increased vibration also seemed to correlate with increased Generator Rotor temperatures. A cross-functional team from the plant’s Engineering, Nuclear Maintenance, System Management, and Instrumentation departments evaluated TDM2/DDM2 vibration data and maintenance history. Additional velocity vibration transducers were installed on the exciter frame and bearing housing, and machine data was collected by the Bently Nevada 208 Data Acquisition hardware.

During the next two weeks, the plant was operated at reduced power levels. The plant’s Evaluation Team determined a shutdown would be required within days, primarily due to the direct correlation of increased vibration to increased generator load. Shaft centerline and orbit plots showed the exciter shaft was rising in the #11 bearing over time and appeared to follow the Generator shaft directly, therefore, the load correlation. A review of the ADRE data for the bearing caps revealed excessive vibration at running speed that had not been there before the refueling outage. The exciter frame was rocking axially; the top of the frame was vibrating four times as much as the bottom of the frame.

Based on the collected ADRE data, plant personnel suspected that the exciter shaft rise was caused by a coupling lock-up on the Falk flexible coupling. They suspected that the 200 ton generator shaft was picking up the 3 ton exciter shaft. This would only occur due to vertical misalignment (exciter lower than the generator shaft) and a rigid coupling. After reviewing generator and exciter shaft centerline plots from the startup, plant personnel suspected that the generator-to-exciter cold alignment offset (exciter 152-203 μm (6-8 mil) high) was not enough.

In addition, post-maintenance documents showed that the exciter frame vibration was being caused by loose support, due to spring in the shim packs, along with a severe soft-foot condition. The loose support was suspected of causing a structural resonance at just above the 1800 rpm running speed.

Problems found during shutdown:

1. The generator-to-exciter coupling gap was incorrect, causing rubbing of the shaft faces.
2. Due to the rubbing, the exciter shaft machined itself into the generator shaft bumper plate, causing the two shafts to rigidly couple.
3. The exciter sole plate pads were not in the same plane, causing soft-foot.
4. There were only two, 1.22 m (48 in) long shim packs on each side of the exciter.
5. The exciter is aligned on a slope, higher at one end than the other, and the long shim packs caused excessive soft-foot.
6. The shim packs had as many as ten shims per pack, which caused the spring and loose support.

All these problems were corrected by designing shim packs which compensated for the differences in the sole plate pads, by increasing the number of shim packs to four per side, by aligning using only the four corner shim packs, by packing the middle shims without changing the elevation, and by decreasing the number of shims in each pack. The coupling gap was corrected by resetting the Limited End-Float Kit, which stabilized the exciter’s magnetic center. As a result, the vibra-

tion levels dropped to normal with no shaft centerline movement.

Recirculation Pump Motor Oil Whirl

When the core flow was increased, high vibration levels caused alarms which necessitated an increase in the Recirculation Pump speed (the Recirculation Pump had never previously been operated above 1520 rpm). Once Danger alarms were received, though, Operators immediately began reducing the pump speed until vibration levels dropped below the alarm setpoints. Engineering was immediately contacted to review vibration data. Spectrum and full spectrum cascade data (Figures 1 and 2) indicate a ½X vibration component and a forward, circular precession of the vibration (negligible reverse vibration components). The orbit (Figure 3), though, clearly shows the classical characteristics of oil whirl: slightly less than ½X vibration frequency, circular shape, forward precession. (A review of the historical data from all the Recirculation Motors showed that oil whirl had previously occurred at approximately 445 rpm, during startup.) At 1520 rpm, vibration levels reached approximately 305 µm (12 mil) pp. Plant personnel decided not to exceed this speed, although this meant that less power would be produced until the next refueling outage in approximately 6 months.

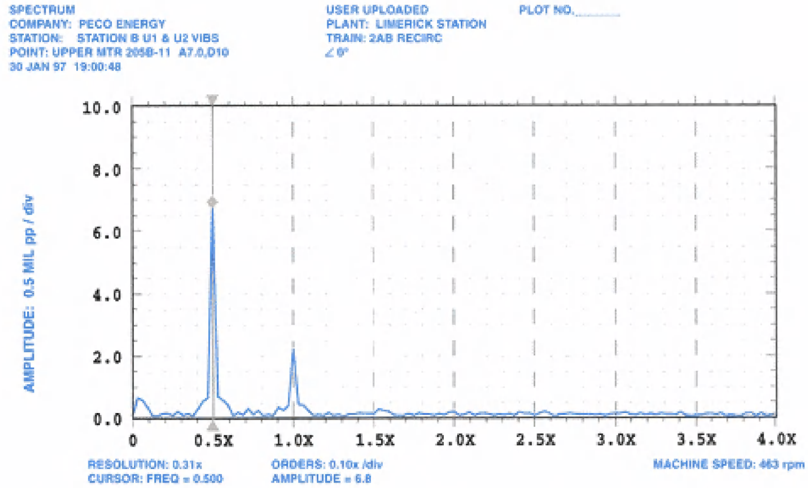


Figure 1. Spectrum taken during recirculation pump startup showing apparent ½X malfunction frequency.

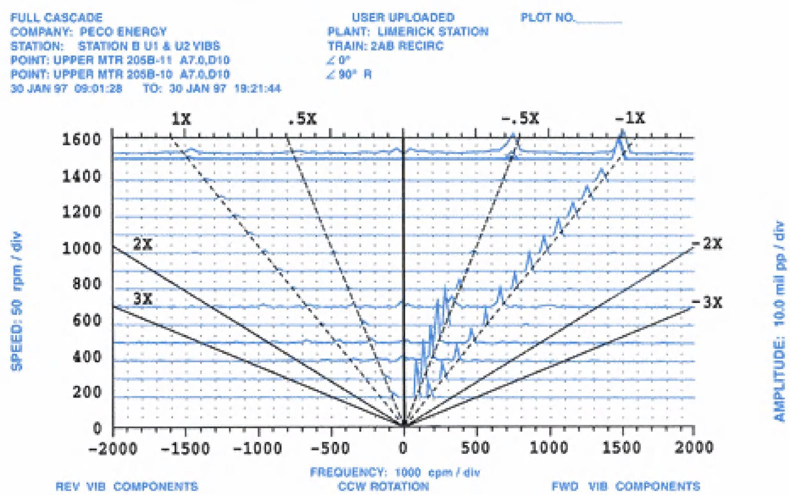


Figure 2. Full spectrum cascade of recirculation pump startup showing forward circular nature of malfunction (negligible reverse components).

To eliminate oil whirl, the upper motor bearing design was changed to a tapered land bearing which was installed during the refueling outage. All signs of oil whirl were eliminated (Figure 4).

Condensate pump bearing realignment

The large 4500 hp motors in Limerick's Condensate Pumps had experienced high vibration levels for quite awhile. When installed, the motors were more than 12 mils per foot out of level, and the motor bearings were believed to be non-concentric. These deficiencies became apparent very quickly via vibration alarms in the Main Control Room. These deficiencies could only be repaired during a refueling outage, but problems had become so severe during the cycle that Engineering needed to provide a short-term solution to minimize vibration and prevent premature bearing failure. A significant amount of vibration diagnostics were performed using ADRE Software and the Dynamic Data Manager.

Analysis of orbit plots revealed a severe rub in the upper motor bearing. The shaft was impacting the bearing in one quadrant. It also appeared there were electrical problems as well. Spectrum analysis revealed sidebands around 1X (running speed) at a frequency equal to the number of poles x slip frequency. This implied a fluctuating air gap. Our goal, as an interim fix, was to somehow reduce the amount of impact on the bearing and allow the rotor to seek a radial center.

The upper motor bearing is a 6 shoe, adjustable guide bearing. Therefore, we were able to calculate a bearing move using orbit analysis. On the orbit plot, we could determine the impact area within the bearing. We needed to move the bearing in the direction of the rub, approximately 102 µm (4 mil). The move was extremely successful in reducing the impact and fluctuating air gap.

Recent installations

Limerick recently installed a Bently Nevada Trendmaster® 2000 System to provide information on their Main Steam lines. The first stage of this installation will provide vibration data from various sections of main steam line piping located by the Main Steam Stop & Control Valves for the Main Turbine. The Trendmaster system allows us to monitor vibration and strain signals from the strain gauges mounted to various beams and struts, and pressure signals from pressure taps in the Main Steam lines. It provides us with spectrum and trend displays of the information.

We are in the process of expanding the Trendmaster 2000 System to include all our Turbine, Reactor and Refuel floor supply and exhaust fans. The next phase will include other balance of plant equipment. These fans and pumps are currently part of our plant's portable data collection (walk-around) program, but we recognize the need for more timely and accurate data. To meet this goal, we plan to continually expand the Trendmaster 2000 System.

Further plans include upgrading our existing TDM2 System by adding the new Bently Nevada Data Manager® 2000 for Windows NT®. All three of our Bently Nevada Systems will then run under Microsoft operating systems.

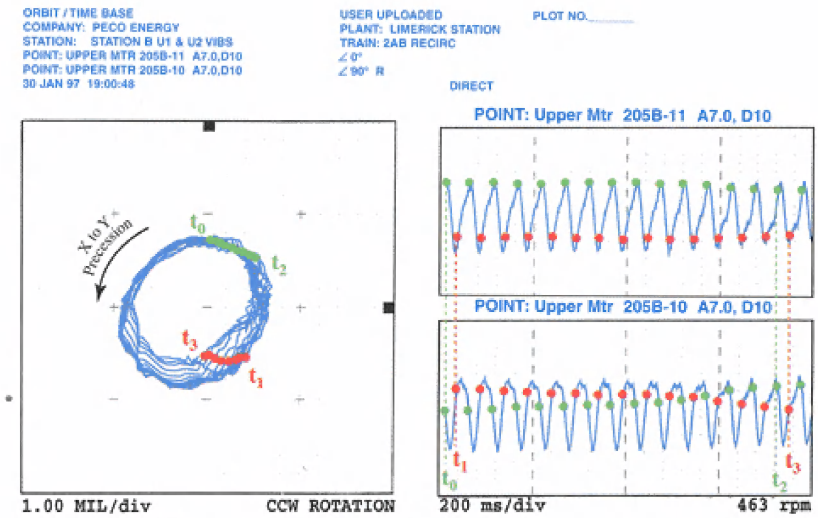


Figure 3. Orbit/timebase taken during recirculation pump startup showing circular, forward precession of malfunction. Slow change of Keyphasor® dot position, against direction of precession, indicates a frequency of slightly less than ½X .

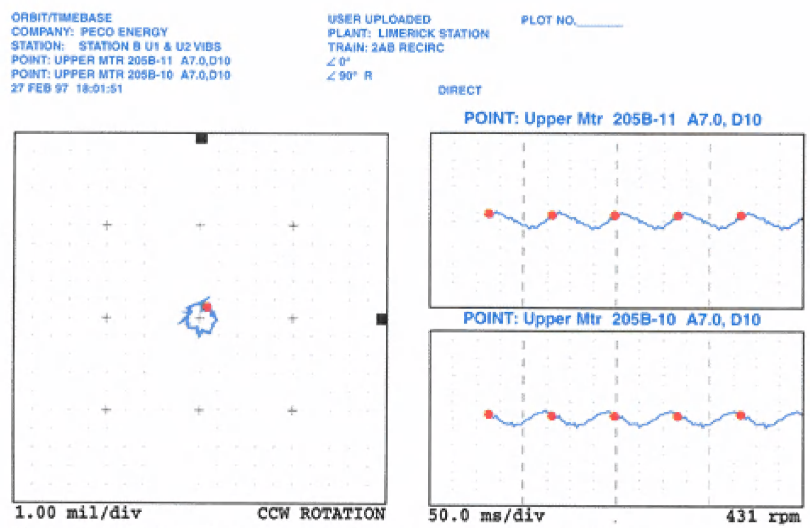


Figure 4. Orbit/Timebase taken during startup of recirculation pump after motor bearing was replaced.

Data Manager 2000 installation

Limerick's Training Center installed Data Manager 2000 four months ago. Having Data Manager running in our MCR simulator is extremely important for Operator training. It allows Operators to train on vibration scenarios due to unexplained transients or expected (normal) vibration responses from the effects of temperature/load changes during machine startup. Since it was not feasible to provide real time data to the simulator, a NetDDE transfer of data simulated an incoming vibration signal to the DM 2000 Software. The vibration signals are simulated by a third party software program that produces vibration signals which represent various startup scenarios.